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THE TOXIC PROPERTY OF BOG WATER AND BOG SOIL

ALFRED DACHNOWSKI

(WITH SIX FIGURES)

The publication of recent work on the existence of injurious substances excreted from roots of plants (**19, 12, 16,**) has necessarily resulted in disclosing to ecologists some overlooked data. Repeatedly it has been shown that the commonly accepted environmental factors are not always sufficient to explain certain important problems of association among plants. It must be admitted, therefore, that there is a problem to be solved not only regarding the relation of one field crop to another, but also with reference to the succession of one plant society by another.

In the study of the structural adaptations of bog plants and the causes of their occurrence in bog areas, various theories have been brought forward. The idea generally current among workers in the ecology of bogs is that the geographical distribution of bogs and the local differences in the flora of bog areas and swamps have probably come about chiefly through post-glacial migrations and changes in the physiography of the habitat. The cause determining the structural characteristics of bog plants is generally understood to lie in the "physiological dryness" of the habitat. But while some writers lay stress upon low temperature of the bog substratum and the presence of drying winds as the prominent factors (**11, 7, 8**), others emphasize humous acids in the soil, abundance of soluble salts, and alkalies (**15**). More recently the effect has been correlated with low temperature and lack of aeration of the subsoil rather than with acidity (**6, 17**).

In 1904, while at work on the ecology of ravines near Ann Arbor, Mich., the writer became convinced that the reactions of plants on their habitat were equally as great and profound, in some cases, as the influence of edaphic and climatic factors. In various places the decomposed remains of an earlier vegetation led to mechanical and chemical changes in the soil, the extent of which was more effective toward breaking up the flora into a heterogeneous formation, accompanied by a frequent replacement of one dominant group by another (3). These reactions of plants seemed still more pronounced in bog societies. During the past year a grant obtained from the Emerson McMillin Research Fund afforded an opportunity to test by physiological methods the nature of plant reactions. The investigation here reported forms a part of a more extended study on the ecology of Buckeye Lake. This brief report is merely intended to reveal the toxic character of bog water and bog soil. A more detailed account, together with data obtained from an inquiry on the possible isolation and identification of the toxic bodies by a method of fractional distillation, will appear later.

Buckeye Lake is situated 40^{km} east of Columbus, Ohio, in a region free from limestone. It is an extensive body of water about 16^{km} long and 1.6^{km} wide, and was formerly known as the Licking reservoir. The reservoir was originally a lake in the glacial drift. Its chief supply today is the south branch of the Licking River. In 1883 and again in 1834 its water surface was raised by forming a dike around the west end. Near the northern bank, and midway between the small towns of Lakeside and Avondale, is a bog island, approximately one-tenth the dimensions of the lake. Soundings which were made to determine the character of the peat gave $9–12^{m}$ as the depth of the island. With its surface vegetation of distinctly northern forms, the island is virtually a water culture on a large scale. The plants are not dependent for any important part of their food on the soil; rooting in the soil at such depth is not possible here. The vegetation presents two well-marked zones: a central one consisting of sphagnum, several species of Carex, Menyanthes trifoliata, Dulichium arundinaceum, Scheuchzeria palustris, Eriophorum, Oxyzoccus, Drosera, Rhus vernix, Aronia nigra, and others; and a marginal zone which includes besides various forms of Salix, Alnus incana, A. rugosa, Ilex verticillata, Cornus canadensis, etc., a few small oaks, and Acer rubrum as the dominant form. Mycorhiza is quite common in both zones. Many plants are strictly hydrophilous, and such plants of the cultivated variety as are grown in either zone for experimental purposes show marked difficulties of absorption, soon become stunted, and often take on xerophilous characters. In the following account these zones are spoken of as the *central zone* and the *maple-alder zone* respectively. The bog water and bog soil used in the experiments were brought every month to the laboratory in glazed earthen-ware jugs from stations which remained identical throughout the period of investigation.

To ascertain the osmotic pressure of the bog water, determinations of the freezing-point were made. As compared with the freezing-point of pure distilled water the average lowering in the various determinations is 0°007 and 0°009 for the central station and the maple-alder station respectively. Compared with similar determinations for Michigan bogs (**13**) the bog water of Buckeye Lake has no higher concentration.

Data on temperature deviations in the bog substratum are omitted here as having no particular significance in the problem at hand in this region. They do not seem adequate to account for the differences, since plants growing in soil, nutrient solutions, or bog water are equally affected. If there is any property of bog water which prevents rapid and successful invasion of plants, this inhibiting influence must rest not in the physical character of the habitat alone, but in some chemical quality as well.

A study of the acidity of the bog water under examination gave results differing but little from those obtained in the Michigan bogs (**13**). Titrations were made with a $n/100$ KOH solution. The bog water from both zones is alkaline to methyl orange and acid to phenolphthalein. A comparison of the acidity figures shows that the bog water of the central station is uniformly less acid than that of the maple-alder zone. Boiling, however, greatly reduces the acidity of the bog water in the latter station. This is due to the escape of carbonic acid. In the light of the results here brought out, the presence of the toxic bodies is not necessarily to be correlated with high acidity.

To determine the presence and possible nature of the injurious substances affecting plants through their toxic effects, the following experiments were planned. Familiarity with the behavior and the conditions of development of *Marchantia polymorpha* (**4**) suggested marchantia gemmae of known history as an indicator for preliminary observations. A large number of gemmae were placed in crystallizing dishes (9.5×4^{cm}) containing 100^{cc} of bog water. Cultures were prepared, containing respectively the untreated bog water from each zone and spring water. The gemmae were allowed to float on the surface of the solutions. An additional series of test conditions was arranged at the same time from the bog water of each zone variously treated. In the table given below, culture medium no. 3 is bog water aerated daily by means of a rubber bulb; no. 4 is prepared by mixing with the bog water dry calcium carbonate and then filtering off the solution; no. 5 is treated by shaking the bog water with carbon (lampblack) and then filtering off the solution; no. 6 is a culture medium obtained by growing in distilled water in battery jars a set of representative plants from each zone. The attempt is made here to simulate undrained bog conditions and to test the water for excretions of roots. To discover whether the effects of poisons were also manifest in the bog substratum, a relatively concentrated aqueous extract was prepared. Quantities of the subsoil from each station were taken from a layer 30^{cm} below the surface vegetation and dried in an oven at a temperature varying between 52° and 60° C. One gram of the material was then mixed with 100^{cc} of distilled water and left standing for several days. The soil solution thus obtained was used as culture medium no. 1. There were thus produced six conditions for each zone in which it was possible to test the bog soils, the excretions of bog plants, the effect of aeration, and toxic ingredients of bog water. The following Table I shows the results of growth in length of marchantia gemmae during a period of twelve and twenty-five days.

It will be noticed that the gemmae made scarcely any growth in the bog soil solution, while in the untreated bog water a fairly good growth occurred. An inhibiting action of these solutions is plainly marked. Evidence of this is further obtained from a microscopic study. For the first five or six days the gemmae made some growth, but after ten days development ceased. Only in the untreated bog water the two opposite growing points of the gemmae were thrifty in appearance. They gradually gave rise to narrow threadlike filaments, which at the end of the twentieth day began to broaden at the tip. In all solutions growth was greatly increased after treatment. Exceptions were noted only when the bog water used was collected just following

TABLE I

MARCHANTIA POLYMORPHA

Culture solution	Growth in 12 days Length in mm.	Growth in 25 days Length in mm.	Remarks
I. Central zone:			
1. Bog soil extract..........	1 and less	......	dead after 8 days
2. Bog water untreated.....	1 -1.5	1.5- 2	filamentous outgrowths
3. Bog water aerated.......	4 -6	6 - 8	
4. Bog water neutral.......	5 -5.5	6 - 7.5	
5. Bog water filtered.......	7.5-8	11 -12	
6. Bog plant water.........	2	5	
7. Spring water............	3 -4	4 - 5	
II. Maple-alder zone:			
1. Bog soil extract..........	1	1 - 2	larger number dead after 12 days
2. Bog water untreated.....	6 -7.5	11	
3. Bog water aerated.......	6 -8	12	
4. Bog water neutral.......	6	10.5-14	
5. Bog water filtered.......	5 -8	10 -11	
6. Bog plant water.........	5 -6	10 -12	

a period of heavy rains, or when the vessels containing the bog water were left uncorked. The differences in growth in the various solutions were less marked, showing that the degree of toxicity at one concentration was entirely different at another. The same is to be said of solution no. 6; its toxic character became more marked with increase in the time during which the bog plants were under cultivation.

Briefly summarized, the data thus far agree in showing (1) that the contrasts in the relative growth of plants in solutions from the maple-alder zone were less marked than those in the solutions from the central zone; (2) that the inhibiting factors of bog conditions are in part due to the presence of injurious water-soluble substances; (3) that the central zone possesses these toxic bodies more decidedly than the maple-alder zone; and (4) that in both zones the toxicity can be corrected by a method of aeration and by the use of calcium carbonate and carbon black.

A series of experiments was next made in the form of bog water cultures with various cultivated plants. Half-liter glass jars of the Mason pattern were used, and prepared in the conventional way. The seeds were germinated in sawdust. Germination in quartz sand and in paraffin-coated disks of galvanized iron wire was found less satisfactory. Transplanting was done when the plants had attained a height of 5–6^{cm}. The culture media used were prepared as indicated for marchantia. From two to six plants were used for 400^{cc} of solution. Each experiment was continued for 7 to 10 days according to the amount of water transpired before renewing the culture solution. The different cultures always stood side by side in the university greenhouse, so as to give uniform environment. The light conditions were the same also; direct sunlight was avoided by cloth screens. In place of temperature and moisture readings, measurements of the evaporation power of the air were obtained from

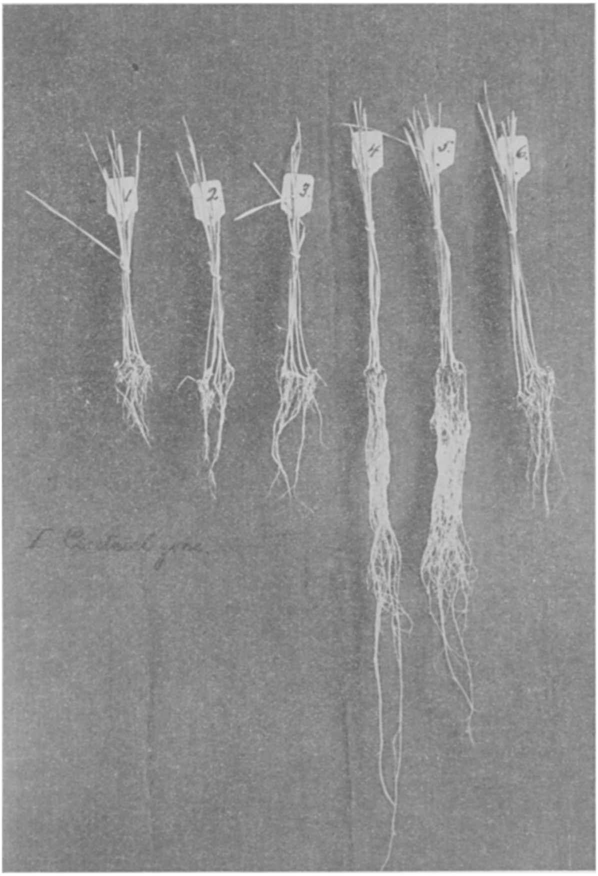

FIG. 1.—Wheat plants from various cultures of bog water and bog soil. Numbers as in the text, p. 133. Six plants from each solution.

the records of two atmometers. The instruments were prepared on a scale as given by LIVINGSTON (14). The integration of humidity, temperature, and air-current data given in a weekly rate varied between 200 and 270^{cc}

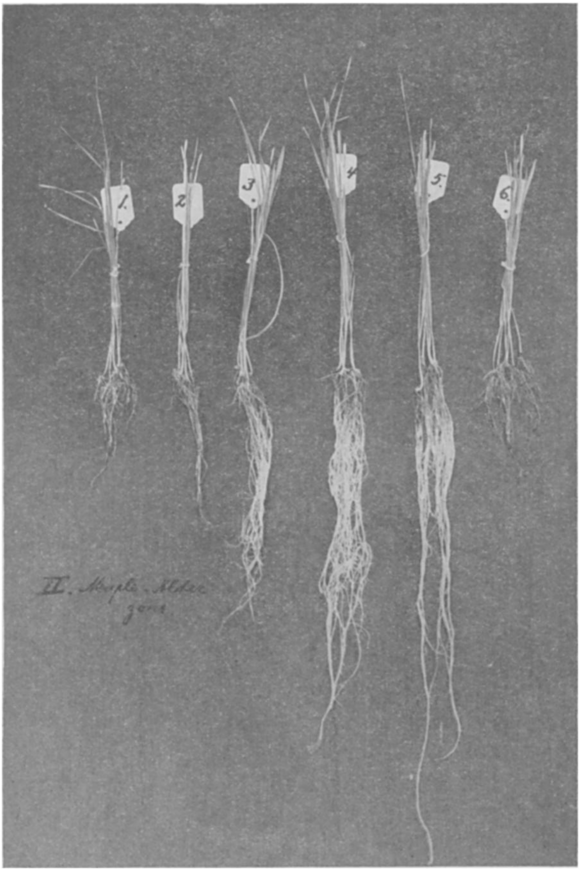

FIG. 2.—Wheat plants from various cultures of bog water and bog soil. Numbers as in the text, p. 133. Six plants from each solution.

As an aid for comparing the rate of growth of similar plants in different media various criteria were used. The main emphasis, however, is placed upon the total transpiration for a definite period of growth, since the difference between the amounts of water lost has been shown to be equivalent to the difference between the physiological value of the solutions (19). Other criteria employed were the condition of the roots, green and dry weight of plants, length and anatomical structure of roots, stem, and leaves. None of these alone can be regarded as accurate measures of plant activity, but taken together they generally agree in indicating the relative value of the results. Without dwelling here at length upon the exact data derived from these experiments, only the results in transpiration-increase are given below in tabular form. The percentage increase in transpiration is calculated for the larger number of the plants upon the basis of the quantities for the bog soil solution considering it as unity.

TABLE II

PERCENTAGE INCREASE IN TRANSPIRATION

Culture solution	Wheat	Corn	Phaseolus	*Vicia faba*	Elm	Buckeye	Cowpea	Oats	Tradescantia
I. Central zone:									
1. Bog soil extract*......	0	0	0	0	0				0
2. Bog water untreated...	19	16	113	22	68	0	0		9.8
3. Bog water aerated.....	55	27	201	...	...	1.3	20		...
4. Bog water neutral.....	209	91	...	100	...	...	...		8.6
5. Bog water filtered.....	245	52	225	215	94	38.8	42		24.7
6. Bog plant water.......	54	22	184	...	...	...			
II. Maple-alder zone:									
1. Bog soil extract*......	0	0	0					0	
2. Bog water untreated...	38	65	287					90	
3. Bog water aerated.....	164	71	...					44	
4. Bog water neutral.....	298	136	335					148	
5. Bog water filtered.....	256	76	...					...	
6. Bog plant water.......	11	40	178					113	

*4^{gm} of bog soil and 400^{cc} distilled water.

An increase in the dry weight of roots and tops was obtained in all plants growing in the solutions treated with $CaCO_3$ and carbon black. For the corn and wheat respectively the increase in the dry matter produced varied from 20 per cent. to 50 per cent. during the time of the experiment.

It will be observed that the evidence derived from wheat, corn, bean, elm, and buckeye seedlings (two years old), and other plants yields results and conclusions similar to those pointed out for marchantia. The plants grown in the bog soil extract and in the untreated bog water show stunting clearly in the roots. The tops of the plants are more nearly alike, except in the stronger solutions. Marked differences in the degree of sensitiveness to toxicity or of the oxidizing power of roots are noticeable for the various plants. Phaseolus and *Vicia faba* proved thus far to be the most plastic plants. In the solutions filtered with $CaCO_3$ and carbon black the tops surpass in development the growth of roots. The plants show marked variations in the internal structure of leaf and stem. Those grown in the bog soil extracts show distinct xerophilous characters. The leaves are reduced in area, thicker, of a deeper green, and with revolute

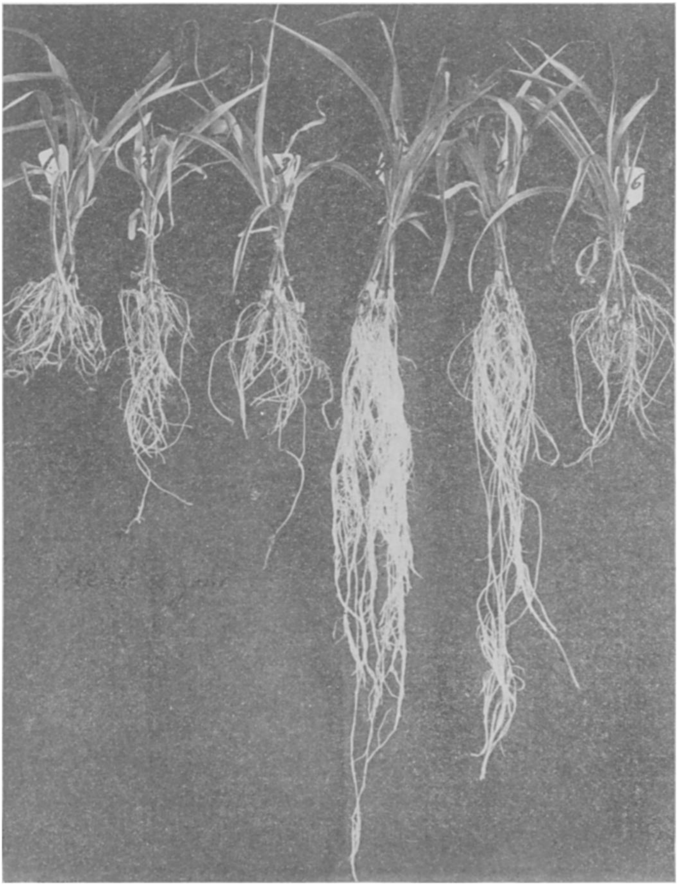

FIG. 3.—Corn plants from the various cultures of bog water and bog soil. Numbers as in the text, p. 133. Four plants from each solution.

margins; responses which cannot be attributed to light but to a reduced transpiration current (**18**) consequent upon the toxicity of the habitat (*figs. 1–6*).

It is worthy of note in this connection that when grown in a 0.01

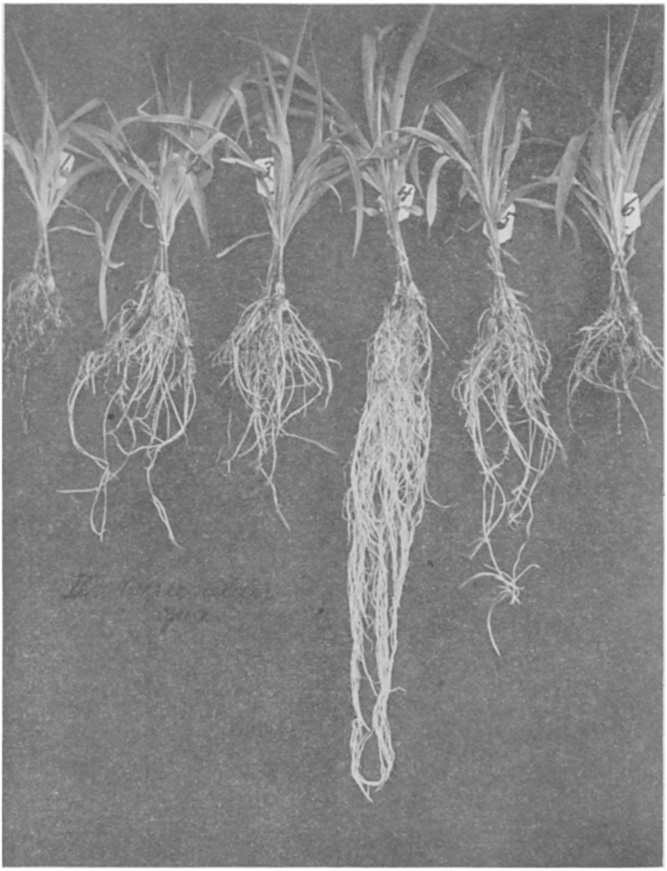

FIG. 4.—Corn plants from the various cultures of bog water and bog soil. Numbers as in the text, p. 133. Four plants from each solution.

per cent. solution of strychnin sulfate, atropin sulfate, or other toxic body of a similar nature and with a high reducing power, the same dwarfing effects are obtained with Phaseolus. When treated with $CaCO_3$ and carbon black the solutions become highly beneficial. The accelerated growth and transpiration are no doubt due to the presence of these substances in small amounts, and the behavior of the plants is very much like those grown in a 0.0001 per cent. solution of strychnin or atropin sulfate.

The striking agreement of results obtained from such a variety of material seems sufficient proof that the factors inhibiting plant growth and plant association and succession are at least in part due to the plants themselves. Carbon black and calcium carbonate add no soluble matter to the solutions (2), hence it becomes certain that the beneficial effects cannot be due to the introduction of nutrient material but to the taking up, i. e., the adsorption of injurious substances present. This would indicate, therefore, that the changes in the soil conditions are produced by noxious substances formed in the absence of O_2. They may be products of decomposition, perhaps they are in part plant excreta, but whatever their nature, they are water-soluble toxic bodies which retard oxidation in the tissues and decrease transpiration, thus causing xerophily, stunting, and even death.

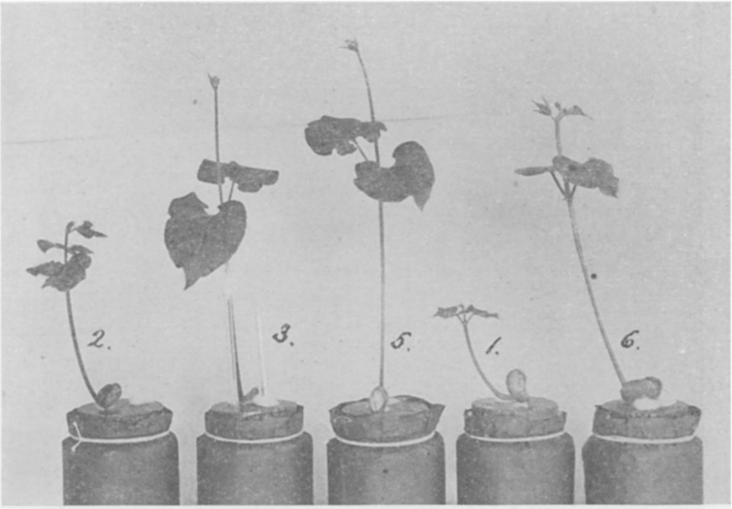

FIG. 5.—Average plants of *Phaseolus multiflorus*, showing effect of bog water variously treated. Numbers as in the text, p. 133.

It may be readily questioned whether part of the response arises from a deficiency of oxygen in the soil. The evidence obtained by

BENNETT (1) is against aerotropism in roots. It follows, therefore, that results reported as due to lack of aeration in the bog substratum are really due to toxicity. Under natural conditions the inhibiting effect is eliminated by aeration, a slow process of oxidation preventing the accumulation of injurious plant excreta in the soil. However, on account of the great demand for oxygen, the process can be carried on efficiently only near the surface. Beneath, the active bodies are more plentiful in the dead material than in the plants themselves. An undrained peat substratum, therefore, must necessarily cause more marked deterioration in development and permit a different association and succession of plants than a drained habitat.

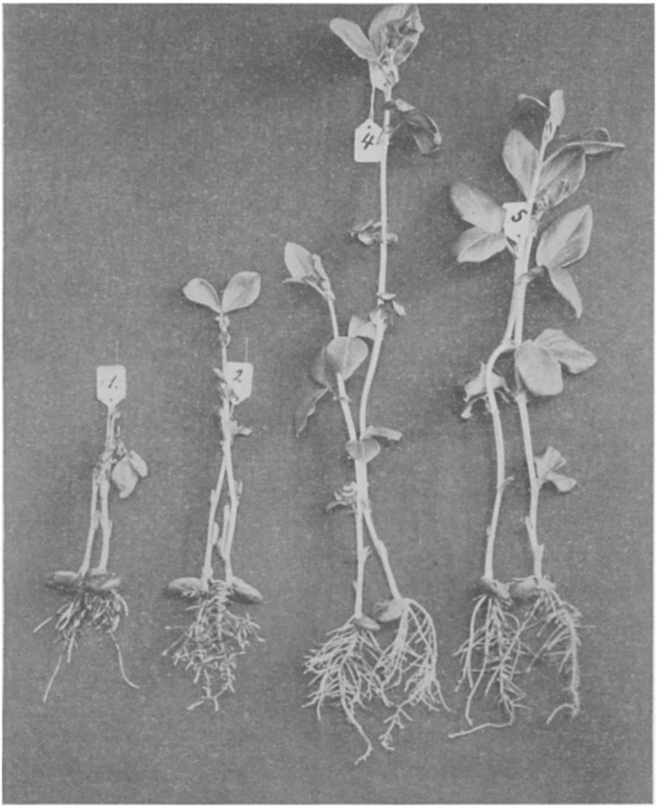

FIG. 6.—*Vicia faba* from cultures of the central zone. Numbers as in text, p. 133. Transpiration data and photograph by Miss FREDA DETMERS.

That the response to toxic bodies when present in small amounts may lead to acceleration of growth has become evident also in connection with a biometric study on the annual wood-increment in *Acer rubrum* (**5**). Measurements upon such trees from the outermost edge of the maple-alder zone as were nearly the same in size, age, concentric growth of wood, and general environment, as similar forms found in woodlots near the shore gave the following differences in the frequencies of rings:

Width of rings in mm	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5
Frequencies in bog-habitat	16	10	23	20	27	12	20	5	7	5
Frequencies in woodlots	26	30	31	9	6					
Width of rings in mm		6	6.5	7	7.5	8	8.5	9	9.5	10
Frequencies in bog-habitat		5	5	6	1	2	0	1	0	2
Frequencies in woodlots										

The mode and the variation constants derived from them are equally interesting:

Habitat	Bog	Woodlots
Mode	3 mm	2 mm
Mean	3.425±0.098	1.701±0.038
Standard deviation	1.870±0.069	0.566±0.027
Coefficient of variability	54.60±2.55	33.28±2.46

We have here the type and the place-habit from two distinct edaphic conditions. The differences in the soil habitat have led to physiological variations which changed not only the type, but the variability and even the sign of the skewness. Quantity and quality of the wood have been affected; as products of the environment they are a measure of environmental conditions.

To attempt to correlate the data with the work of previous authors on toxic action is obviously impossible. Definite knowledge of the chemistry of bog water and bog soils is lacking at present. There are always present a great variety of chemical and biological agents, and products of decomposition, which may react collectively. Hence definite conclusions cannot be based upon the results obtained here. The limited extent to which these experiments have been carried, gives no more than a suggestion of the possibilities.

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